

LEVEES AND CHANNELS TECHNICAL TEAM
Seismic Susceptibility Sub-Team

SPECIAL CALFED REPORT

SEISMIC RISK ASSESSMENT

OF THE

SACRAMENTO-SAN JOAQUIN DELTA LEVEE SYSTEM

Section 3.6:

ESTIMATES OF LEVEE FRAGILITY

DUE TO EARTHQUAKE SHAKING

DRAFT No. 3

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3. VULNERABILITY OF DELTA LEVEES

3.6 ESTIMATES OF LEVEE FRAGILITY DUE TO EARTHQUAKE SHAKING

3.61 Introduction

Estimates of Delta levee fragility during different earthquake loadings were developed by members of the Seismic Susceptibility Sub-Team of the CalFed Levees and Channels Technical Team. Levee fragility is defined as a measure of the susceptibility of a levee to fail during a particular seismic loading. Members of the sub-team reviewed available geotechnical information associated with levees in the Delta and assessed the relative vulnerability of the levees and their foundations to earthquake shaking. Sub-team members also reviewed previous seismic stability studies of various areas in the Delta. The efforts of the sub-team were facilitated by geotechnical reports and data supplied by the California Department of Water Resources, U. S. Army Corps of Engineers; Kjeldsen Sinnock & Neudeck, and Murray Burns & Kienlen.

3.62 Process

The process for assessing potential levee failures during earthquakes was to review the available information and to develop a range of estimates for the number of levee failures that might occur for various levels of earthquake acceleration. This levee fragility was expressed in a normalized form as the number of expected levee failures per 100 miles of levee. Different ranges of fragility were estimated for different regions in the Delta, and for different levels of earthquake shaking. This information is used in a later section, together with the probabilistic seismicity estimates, to develop the number of failures likely within an exposure period.

Failure was defined as sufficient distress to the levee in the form of slumping and/or cracking that would lead to a complete breach and uncontrolled flooding of the island. Failure was considered to occur either during the earthquake, or within a very short period of time following the earthquake. Levees could be extensively damaged by earthquake shaking and lack of repair, but unless a breach of the levee resulted, failure was not considered to have occurred.

Precise quantitative estimates of levee failures cannot be made because geotechnical information for over 600 miles of levees remains limited, particularly for the levees themselves. The sub-team members relied upon the available information and their individual knowledge and experience to develop individual assessments of the frequencies of levee failure for different levels of earthquake shaking. These individual assessments were then discussed by the sub-team and refined into a single consensus range of values.

3.63 Earthquake Motions Considered

The likely range of bedrock/stiff soil motions that might be experienced on an outcrop of such materials within the Delta within the next 30 to 300 years is between 0.05 and 0.30g (see Chapter 2). Such motions are expected to be generally associated with a Magnitude 6 event. However, the Delta has thick and deep deposits of soft organic and mineral soils overlying the top of bedrock and/or stiff soils. Layers of soft soils overlying stiffer deposits are generally expected to amplify earthquake motions developed in the deeper, stiffer deposits. Based on the studies by DWR (1992) and Boulanger et al. (1997), the most likely acceleration amplification factors between deep base layers to levee crown range between 1 and 2. For the purposes of the current assessments, an average amplification factor of approximately 1.6 was used. This crown amplification accounted for both soft soil amplification as well as topographic amplification. Accordingly, the earthquake parameters considered in these fragility assessments can be summarized as follows:

Earthquake Magnitude: 6.

Peak Bedrock/Stiff Soil Outcrop Accelerations: 0.05 - 0.30g.

Base Layer Outcrop to Levee Crown Amplification Factor: 1.6.

Magnitude scaling factors to correct the acceleration levels for earthquakes having magnitudes other than Magnitude 6 were incorporated in the probabilistic seismicity analyses (see Chapter 2).

3.64 Damage Potential Zones

Qualitative relative assessments of high, medium, and low failure potential during earthquake shaking were made for different regions within the Delta. Geotechnical parameters affecting this assessment included the following:

- The presence of loose, cohesionless sandy and silty layers in the levee embankment generally lead to a high or medium high failure potential rating. Such soils are liquefiable when saturated. Due to the fact that the levees are manmade and not formed by intermittent natural processes, such materials are expected to have greater lateral continuity within a levee than in a natural deposit. The presence of such soils beneath the phreatic line within the manmade levee embankment, as detected by penetration testing, indicates a relatively high potential for a liquefaction-induced levee failure. Levees with substantial amounts of liquefied material are likely to exhibit flow slides and lateral spreading as very loose, cohesionless soils have low post-liquefaction shear strengths.
- The presence of loose, cohesionless sandy and silty layers in the levee foundation was also considered detrimental because of the potential for liquefaction. However, it was not considered as serious as having such materials within the levee. This is because such layers within the natural foundation are more likely to be discontinuous.

Foundation liquefaction beneath a levee is also generally less critical than potential liquefaction within the levee embankment as the post-liquefaction shear resistance necessary to prevent flow and lateral spreading is lower due to geometry and net driving force considerations. In addition, somewhat higher penetration resistance is commonly reported for such foundation layers and this suggests somewhat higher liquefaction resistance and post-liquefaction shear strength.

- High levees on thick, soft foundations were considered more fragile because of their potential to have only marginal static stability. Statically marginal sections were considered to be likely to slide and experience significant displacements during earthquake shaking even without liquefaction.
- Levees with narrow cross sections, limited freeboard, or histories of previous distress were also considered to have a higher probability of failure. For example, the more compacted and robust Project Levees were considered more stable than the majority of the Local Levees.

Two modes of earthquake-induced levee failure were considered while developing the different damage potential zones: 1) Flow slides and lateral spreading associated with strength loss (liquefaction) of levee embankment or foundation soils, and 2) Inertially-induced seismic deformations of levees experiencing no liquefaction. Potential failure mechanisms included overtopping, seepage erosion due to cracking, and exacerbation of existing seepage problems due to deformations and cracking. Seasonal variations in river and slough water elevations, and their interactions with tides, were also considered. This evaluation resulted in dividing the Delta area into four Damage Potential Zones as described in Table 3.61 and shown in Figure 3.61.

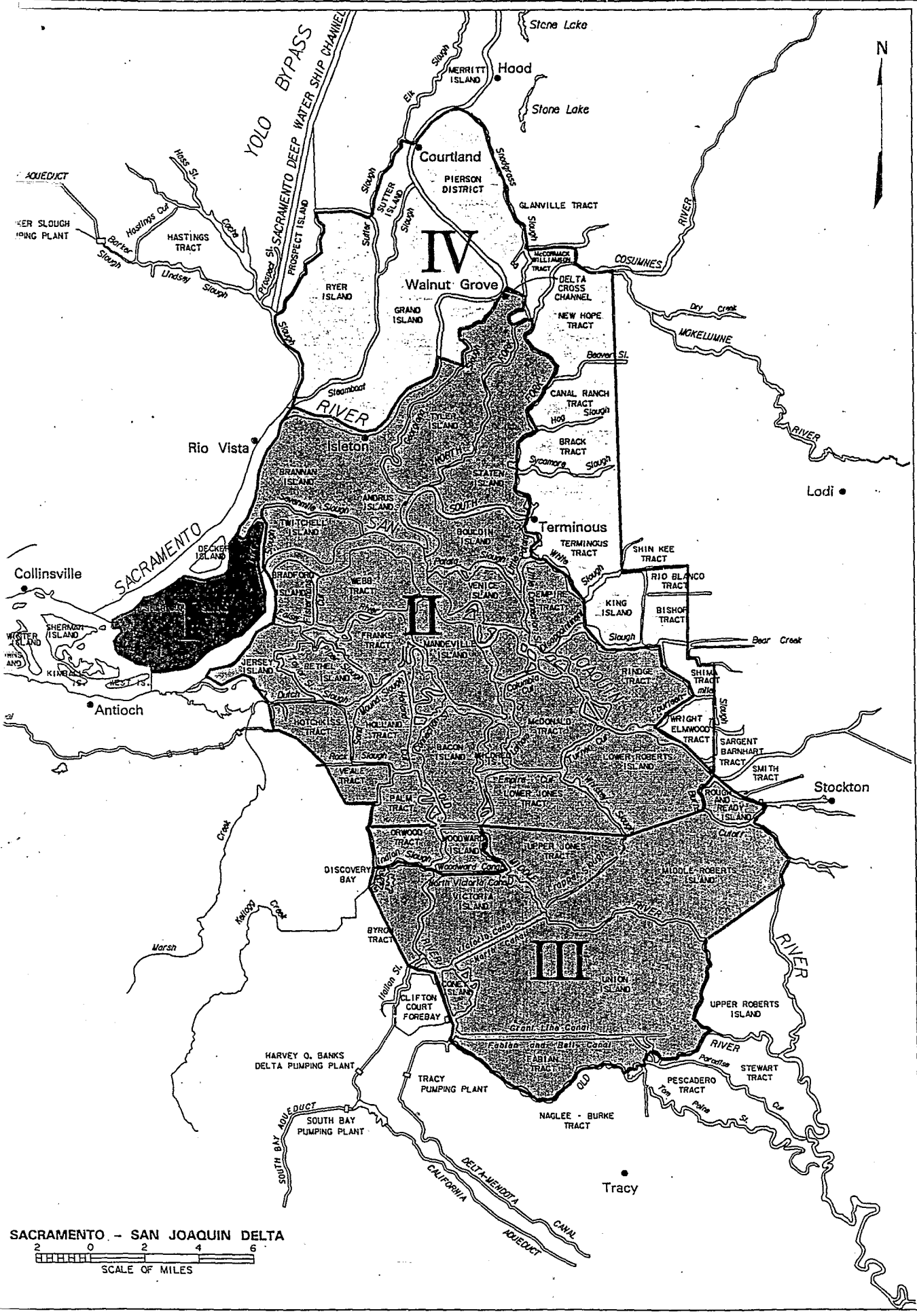
3.65 Estimates of Liquefaction-Induced Levee Failures

The liquefaction fragility estimates (failures per 100 miles of levee) were developed by the sub-team for different earthquake loadings based on the sub-team's experience with the performance of similar earth structures. For peak accelerations less than 0.1g, the fragility values are relatively low. This is in good agreement with the lack of Delta levee failures caused by historical earthquakes. Peak base accelerations from historical earthquakes have been estimated to have been less than about 0.08g since reclamation of the Delta began in 1868 (see DWR, 1992). However, as base accelerations (seismic loading) increase, the estimated levee fragility also increases for all four damage potential zones.

One of the important results from the liquefaction fragility estimates is that this mode of failure is much greater for Zone I (Sherman Island) than for the other three zones. This is because extensive layers of liquefiable sandy soils are known to exist within the south levee of Sherman Island. No other levee is known to have such a large extent of liquefiable soils present in the levee embankment.

TABLE 3.61: DAMAGE POTENTIAL ZONES WITHIN THE DELTA

Damage Potential Zone	Levee Length in Zone (miles)	Description
I	20	<u>High susceptibility</u> to earthquake-induced levee failure. This zone encompasses only Sherman Island and was considered to have high potential for failure due to the presence of substantial liquefiable soils within the south, local levee along the San Joaquin River. This levee reach has an unusually high amount of cohesionless sandy and silty soils within the levee section, is relatively narrow, is founded on thick deposits of soft soil, and has a history of distress.
II	301	<u>Medium to medium-high susceptibility</u> to earthquake-induced levee failure. This zone is within the central Delta and generally includes levees with high sections founded on thick deposits of soft soil. Most of the levees which have had histories of distress or that have failed during flood events are located within this zone.
III	116	<u>Low to medium susceptibility</u> to earthquake-induced levee failure. This zone is located on the southern and western periphery of the Delta and generally involves levees of smaller heights founded on thinner layers of soft soil.
IV	181	<u>Low to medium susceptibility</u> to earthquake-induced levee failure. This zone is located on the northern and Eastern periphery of the Delta and generally involves levees of smaller heights founded on thinner layers of soft soil.
TOTAL LENGTH	618	



SACRAMENTO - SAN JOAQUIN DELTA
 2 0 2 4 6
 SCALE OF MILES

3.66 Estimates of Levee Failures for Non-Liquefaction Earthquake-Induced Displacements

The sub-team also believed that marginally-stable levees might deform sufficiently during an earthquake and result in a failure even if the levee and foundation soils did not experience liquefaction. The sub-team estimated levee fragility for the non-liquefaction deformation mode of failure using the following approach:

- The sub-team first estimated the number of marginally stable levee sites in each Damage Potential Zone. Three levels of marginal stability were considered and the number of marginal sites for each level was estimated for each zone.
- The levee deformation that would be induced by earthquake shaking was estimated for each level of marginal stability using one-dimensional dynamic response analyses coupled with Newmark-type double-integration deformation calculations. Levee deformation estimates were generated for a range of base accelerations.
- The estimated levee deformations were then converted into probabilities of failure using an approximate relationship developed by the sub-team. The failure probabilities were then summed for each level of marginal stability within a zone, and then expressed as a levee fragility in terms of failures per 100 miles of levee within each zone for a range of base accelerations.

3.67 Estimates of Levee Fragility during Seismic Events

Table 3.62 presents levee fragility values estimated for both liquefaction and non-liquefaction deformation modes of failure. In comparison with the liquefaction mode of failure, the deformation levee fragility values are much lower, approximately 20 percent of the liquefaction values. In addition, while there is a significant difference in the liquefaction fragilities estimated for the different zones, there is not that a large difference in the deformation fragilities. This is principally because the number of marginally stable sites per levee mile are believed to be about the same within both Zones I and II in the central Delta.

TABLE 3.62: ESTIMATED FAILURE RATE (FRAGILITY) FOR BOTH LIQUEFIED AND NON-LIQUEFIED REACHES - FAILURES PER 100 MILES

Magnitude 6.0 Rock/Stiff Soil Peak Acc. (g)	Damage Potential Zone	Levee Length (miles)	Estimated Fragility - Number of Levee Failures per 100 miles			
			Liquefied Reaches		Non-Liq. Reaches	
0.05	I	20	0.005 -	0.50	0.030 -	0.075
	II	301	0.001 -	0.083	0.030 -	0.072
	III	116	0.001 -	0.034	0.007 -	0.024
	IV	181	0.001 -	0.033	0.006 -	0.024
0.10	I	20	0.20 -	2.5	0.050 -	0.115
	II	301	0.080 -	0.33	0.046 -	0.104
	III	116	0.050 -	0.17	0.010 -	0.038
	IV	181	0.050 -	0.17	0.008 -	0.033
0.15	I	20	2.5 -	10.	0.16 -	0.35
	II	301	0.66 -	1.7	0.14 -	0.30
	III	116	0.35 -	1.4	0.031 -	0.12
	IV	181	0.33 -	1.3	0.021 -	0.10
0.20	I	20	5. -	20.	0.36 -	0.77
	II	301	1.7 -	5.0	0.32 -	0.66
	III	116	0.86 -	2.6	0.069 -	0.27
	IV	181	1.1 -	2.8	0.046 -	0.23
0.30	I	20	15. -	30.	1.5 -	3.2
	II	301	5.0 -	10.	1.3 -	2.7
	III	116	2.6 -	6.9	0.29 -	1.1
	IV	181	2.8 -	6.6	0.19 -	0.95